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Shooting Performance as a Function of Shooters' Anthropometrics, Weapon Design Attributes, Firing Position, Range, and Sex

by Paul L Shorter, Frank Morelli, and Samson Ortega

ARL-TR-7135 **October 2014**

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Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

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Paul L Shorter, Frank Morelli, and Samson Ortega
Human Research and Engineering Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: October 2014	**2. REPORT TYPE**: Final
3. DATES COVERED (From - To): September 2013	
4. TITLE AND SUBTITLE: Shooting Performance as a Function of Shooters' Anthropometrics, Weapon Design Attributes, Firing Position, Range, and Sex	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S): Paul L Shorter, Frank Morelli, and Samson Ortega	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): US Army Research Laboratory, ATTN: RDRL-HRS-B, Aberdeen Proving Ground, MD 21005-5425	**8. PERFORMING ORGANIZATION REPORT NUMBER**: ARL-TR-7135
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study evaluated the combined effects of a shooter's anthropometric dimensions, weapon design attributes, firing position, range, and sex on marksmanship. The US Army Research Laboratory M-Range live fire test facility was used to conduct the study. Study participants consisted of a random sample of 26 Army Soldiers recruited from the US Army Research, Development and Engineering Command Solider Support program. The study participants fired the M16A2 rifle, M4 carbine, and the Heckler & Koch (HK) G36—weapons that feature different barrel lengths and weights. Shooters were asked to fire at 50-, 100-, and 150-m targets. The multiple regression analysis indicated a high degree of correlation among the independent variables; however, the results also indicated that isometric strength, hand length, and rightward horizontal neck rotation may predict shooting performance under time pressure while firing from either a reflexive firing position or a prone firing position. Shooting performance was measured in terms of hit ratios and the radial error from a designated aimpoint. A multiple regression analysis was performed to develop a mathematical model that expresses shooting performance as a function of associated anthropometric data, weapon design data, firing posture, range and sex.

15. SUBJECT TERMS

Soldier shooting performance, anthropometrics, weapon design, range, sex

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Paul L Shorter
Unclassified	Unclassified	Unclassified	UU	38	**19b. TELEPHONE NUMBER** (*Include area code*): 410-278-5878

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The authors wish to thank all those who made this effort possible:

- Soldiers from the US Army 7th Infantry Division, Fort Lewis, Washington, who volunteered to participate in this study, and their chain of command that facilitated their participation.
- Ms Melissa Schafer and Mr Karl Gerhart, US Army Research, Development and Engineering Command, for supporting the study participant requirement through interface with US Army Forces Command.
- Mr Thomas Fry and Mr Douglas Struve, US Army Research Laboratory (ARL), for providing range support, ensuring the uninterrupted execution of study conditions.
- Mr Edmund Baur, ARL, for developing target presentation algorithms, executing target presentation, and processing shooting performance data for statistical analyses.
- Ms Jennifer Swoboda and Ms Patricia Burcham, ARL, for measuring and recording participant range of motion and anthropometric data.

1. Background

The motivation for this study was based on observations made during live-fire experimental trials where shooters of varying physical stature employed firearms in subtly different firing postures. The significance of this observation is that acquisition programs, including small arms acquisition, are usually required to develop systems that can accommodate Soldiers across the full range of categorical anthropometric extremes (e.g., 5th percentile stature and 95th percentile stature); however, the link between the accommodation and performance is not well understood and as a result, not linked into requirements. Findings from this study will serve to link those 2 parameters and may inform small arms materiel development and related combat development.

Numerous studies have been conducted on assault weapon design ergonomics; however, the emphasis has been primarily placed on system design parameters (e.g., weight, length, caliber).[1–3] While these efforts provide valuable insight, anthropometric parameters were limited to mean height, weight, and sex. None of the studies related shooting performance in the context of human systems interface. Furthermore, the test facilities used in those studies lacked the sophistication and breadth of capabilities as compared to the US Army Research Laboratory's (ARL'S) live-fire test facility (M-Range) and were therefore limited in the type of performance metrics that could be collected. The M-Range facility enabled the capture of a broader range of performance metrics with greater precision, thus increasing the precision of possible correlations.

2. Research Objective

The research objective was to use statistical methods to develop a mathematical model that expresses shooting performance, as measured by hit ratio and accuracy, as a function of a shooter's anthropometric dimensions, sex, shooting posture, weapon characteristics, and range.

The variable, sex, was explicitly included, pursuant to recent Department of Defense policy pertaining to permitting female Soldiers to be assigned to direct combat roles.

3. Instrumentation and Facilities

3.1 M-Range Facility

The ARL, Human Research and Engineering Directorate (ARL-HRED), M-Range Shooting Performance Facility M-Range is a live-fire shooting range used to evaluate shooting performance of firearms, 0.50 caliber or less. It consists of 4 parallel firing lanes with target

positions from 10 to 550 m on the 2 left lanes and targets from 10 to 1000 m on the 2 right lanes. Figure 1 provides an aerial photograph of ARL-HRED M-Range. Target control is automated using customized computer algorithms, which enable the operator to program target presentation and record shooting events. The target positions can support a variety of target types, e.g., E-silhouettes and Ivan targets, which are presented and retracted by pneumatically operated arms. Target control parameters include target sequence, range, presentation time, and duration, and can be varied to accommodate a broad selection of shooting study scenarios. Shooting events are recorded by shot microphones placed at the shooter's position and behind each target. The supersonic projectile of each shot, whether firing in semiautomatic or full-automatic mode, generates a shock wave which is detected by the microphones. The time of the shock waves are used to triangulate shot location, accurate to within 5 mm, and expressed as an x-y coordinate relative to the target plane. Shock waves from shots that miss the target by up to approximately 1 ft are also captured. Projectiles with subsonic velocities do not generate shock waves and are therefore not recorded by computer automation.

Fig. 1 ARL-HRED M-Range shooting performance research facility

3.2 Weapons, Ammunition, and Sighting Optic

This effort employed 2 US Army weapons—the M16A2 assault rifle and the M4 carbine— and one foreign weapon, the HKG36. These 3 weapons were selected because their respective lengths and weights represent an ordinal continuum that supported the research objective of developing a mathematical model for shooting performance. The 3 weapons use M855, 5.56- × 45-mm ammunition and were equipped with the M68 close combat optic (CCO), which uses a collimated red dot as the reticle. Figure 2 illustrates all 3 weapons and the M68 CCO.

Fig. 2 Weapons and sighting optic

4. Participants

A total of 26 Soldiers (10 female, 16 male) from the 7th Infantry Division, Fort Lewis, Washington, were employed in this study. Participants were not required to have any specific military occupational specialty, but they were required to be experienced shooters who had successfully qualified with a rifle within the past year. All Soldiers had qualified with an M4 carbine within 4 months of the study. None of the Soldiers had qualified with either the M16A2 or the HKG36. Soldiers were scheduled to arrive at M-Range daily in same-sex pairs of 1 noncommissioned officer and 1 enlisted person. The Soldier pairs arrived at Aberdeen Proving Ground the night prior to participating in the study to ensure they were properly rested and ready to perform as needed.

5. Procedure

5.1 Prestudy Orientation and Informed Consent

Participants who volunteered for the study were given an orientation on the live-fire facility, and the purpose and details of their participation. To ensure the voluntary nature of their participation, participants were provided an informed consent form for review and signature, which explained the details of the study and that they could withdraw from the study at any time without consequence.

5.2 Demographics, Anthropometric Measures, and Visual Acuity

Demographic, anthropometric, and visual acuity data were measured and recorded for each participant. These forms and all data recorded using these forms were secured in a locked physical filing system and password-protected digital filing system. Data that were transferred to digital form for analysis did not include accompanying information (e.g., height and weight) that could be used to identify individuals participating in this experiment. Instead, data processed during analysis were examined in aggregated form.

Standard visual acuity techniques using appropriate Snellen charts were used to determine uncorrected and habitually corrected monocular and binocular visual acuities. This study used the acceptance criteria for visual acuity cited in Army Regulation (AR) 611-101, *Commissioned Officer Classification System*.[4] The criterion cited indicates that participants must have at least 20/20 correctable vision in one eye and 20/100 in the other.

Ocular dominance was determined using the Miles sighting method. The procedure for this method required that the observer extend both arms, bring both hands together to create a small opening, then with both eyes open view a distant object through the opening. The observer then alternates closing the eyes or slowly draws opening back to the head to determine which eye is viewing the object (i.e., the dominant eye). Participants were also asked to report their normal shooting eye and shooting handedness.

Anthropometric dimensions, range of motion, and strength metrics were measured next. The study team organized into 2 stations, one to measure and record anthropometric dimensions and range of motion, the other to measure and record strength metrics. A description of the measuring techniques is included with a description of the independent variables in the following paragraphs. To ensure that the Soldiers would perform without interference of any extraneous effects from this portion of data collection, they were allowed sufficient time to recover from any stress experienced from the measuring procedures.

5.3 Range Familiarization

Upon completion of the prestudy orientation, informed consent, and initial data collection (demographics, visual acuity, and anthropometric measures), the Soldiers were thoroughly briefed on how the live-fire trials were to be executed and all M-Range standard operating procedures and relevant safety requirements.

5.4 Target Presentation

Range familiarization also included an explanation of the target presentation scheme. The target presentation scheme was intended to produce shooting conditions similar to those in an operational environment to the extent possible within the M-Range facility. Target presentation, using E-silhouettes, occurred in pairs and were randomized in terms of distance, latitudinal position (i.e., left, center, right), and sequence time to induce the participants into a rapid decision-making state.

Each experimental condition presented 60 targets presented in pairs (i.e., 30 presentation pairs), at ranges of 50, 100, and 150 m. The pair of targets was randomly presented at the same range or at different ranges and at different latitudinal positions. The pair of targets were not simultaneously presented but rather in sequence at intervals of 2–4 s (i.e., sequence time of 2–4 s). Participants fired one round per target upon presentation. Each target retracted upon being hit or after 3.5 s, whichever occurred first. Subsequent target pairs were presented 2–4 s after the second target of the previous target pair had retracted. Based on prior dismounted warrior research,[5–7] target exposure and sequence times of these durations force shooters into a rapid target acquisition-decision-action process that is sustained throughout an experimental live-fire target engagement scenario. Shooting performance was collected from all 60 targets. Participants were using two 30-round magazines to fire at the targets. Target presentation momentarily paused after 15 presentations, long enough for the participant to reload.

5.5 Weapon Zeroing

The weapons to be used in the study were then zeroed. Each Soldier was provided 1 of each of the 3 weapons, equipped with an M68 CCO to use for the entirety of the shooting trials. The Soldiers zeroed the weapons according to established zeroing procedures as specified within the respective weapon field manuals. All participants were able to zero their weapons within the 30-round limit criterion that had been established for the study.

5.6 Fire for Training and Fire for Record

Study trials were conducted upon completion of the informed consent, initial data collection (demographics, visual acuity, and anthropometric measures), range familiarization, and weapons zeroing.

Study trials consisted of a training session, immediately followed by firing for record. Both sessions entailed firing at targets presented as described in the preceding paragraphs. All shots were electronically recorded by the M-Range command and control center; however, only shots from firing for record were used for analysis.

In some circumstances, participants were photographed solely for the purpose of illustrating different impairment conditions and human performance data for the purposes of this evaluation. In such cases, the participant photographed was informed and given the option of having the photograph destroyed.

6. Experimental Design

The study objective was supported by the variables, study conditions, and the trial matrix defined in the following paragraphs.

6.1 Independent Variables

6.1.1 Anthropometric Dimensions

The selection of anthropometric attributes in this study was predicated, in part, on findings from a study[8] conducted on law enforcement personnel using handguns. That study found significant correlations between shooting performance and anthropometric attributes placed in 1 of 3 groups: hand strength and endurance, hand size, and the shooters' level of fitness (obtained from department physical training).

Because the proposed study examined the use of assault rifles, additional anthropometric dimensions were considered. To effectively employ a rifle, a shooter must be able to hold and operate the rifle, acquire a target and stabilize the rifle to aim at the target, and maintain a shooting posture to reacquire subsequent targets, repeatedly. The research team selected anthropometric attributes that directly relate to employing a rifle as described previously, based on observations from other shooting studies. The anthropometric attributes were placed in 1 of 3 groups: Arm and Hand Length and Ratio Parameters (8), Range of Motion Parameters (4), and Strength and Endurance Parameters (4), to be measured using procedures defined in the Measurer's Handbook: US Army Anthropometric Survey 1987–1988.[9]

6.1.2 Arm and Hand Length and Ratio Parameters

A measuring tape was used to determine these parameter values.

- Grip reach
- Shoulder-elbow length
- Forearm-hand length

- Hand circumference
- Hand length

6.1.3 Ratios Relative to Grip Reach

The arm and hand length parameter values were used to determine these ratios.

- Shoulder-elbow length to grip reach
- Forearm-hand length to grip reach
- Hand size (circumference, length) to grip reach

6.1.4 Range of Motion Parameters

Range and motion parameters were measured by using commercially available electronic goniometers. Sensors were attached to the volunteers' flexion points, which detect changes in joint angles. The changes in joint angles were measured, translated, and reported by a goniometer interface box. The following range of motion parameters were measured:

- Horizontal range of motion for the neck
- Horizontal range of motion for the torso
- Internal and external rotation of the shoulders
- Back flexion

6.1.5 Strength and Endurance Parameters

The following strength and endurance parameters were measured:

- Shoulder strength, maximum dynamic contraction. A dynamometer was used to measure this parameter.
- Shoulder strength, isometric contraction. Isometric contraction was measured by the amount of time a participant could hold a 10-lb weight with his/her support hand (i.e., hand used to support the rifle while shooting) with arm extended forward and parallel to the floor.
- Shoulder strength, endurance. Endurance was measured by the maximum number of push-ups to muscle failure a participant could accomplish.
- Grip strength. A dynamometer was used to measure this parameter.

6.1.6 Weapon Design Characteristics

Weapon design characteristics of interest in this study were weight (kg), length (cm), and recoil (ft lb).[10] The design characteristics for the 3 weapons employed are shown in Table 1.

Table 1 Weapon design characteristics

Weapon	Length (cm)	Weight (kg) (no magazine)	Recoil (ft lb)
M16A2	100.66	3.54	3.30
M4	83.82	2.88	4.39
M4	75.69	2.88	4.39
HKG36 (extended stock)	72	2.82	4.05
HKG36 (retracted stock)	50	2.82	4.05

6.1.7 Range

Targets were presented at ranges of 50, 100, and 150 m in the manner previously described.

6.1.8 Shooting Position

Prone: Shooting while lying on one's stomach with the support hand beneath the rifle, pointed forward. Shooters fired at targets from that position upon target presentation.

Reflexive[11]: Shooters stood in the low-ready position with the weapon barrel pointed down at a 45° angle. Shooters fired at targets from that position upon target presentation.

- Rationale for position selection: It was hypothesized that shooting position affects the shooters' ability to stabilize the weapon enough to hit the intended target. The prone position and reflexive firing position represent the most steady and least steady shooting positions, respectively. Therefore, it was assumed that data collected from these positions would represent end points, capturing the range of possible shooting position effects.

6.1.9 Participants' Sex

Male and female.

6.2 Dependent Variables

6.2.1 Hit Ratio

Calculated by dividing the number of targets hit by the total number of targets presented. A hit ratio was calculated for each test condition.

6.2.2 Accuracy

The paired coordinates of each shot placement, electronically captured by the M-Range command and control center, were converted into mean radial error (MRE) values with respect to the designated aimpoint, with x-y coordinates (0.0, 20.25).

6.3 Experimental Conditions and Test Matrix

There were 6 experimental conditions (A1–C2) based on the weapon and firing position employed. The experimental conditions are illustrated in Table 2.

Table 2 Experimental conditions

Shooting Position	HKG36	M16A2	M4
Prone	A1	B1	C1
Reflexive	A2	B2	C2

This study employed a repeated measures incomplete counterbalanced design, supported by a trial matrix, which provides each study participant a unique firing order to counter potential order effects. The trial matrix is illustrated in Appendix B.

7. Data Analysis

7.1 Data Stratification

In total, the trial matrix produced 468 observations. The dependent variables, hit ratio, and accuracy, were calculated for each cross-tabulation of participant (26), posture (2), weapon (3), and range (3).

As described previously, the target presentation consisted of 60 targets for each participant, weapon, and posture. Subsample sizes for range varied from 5 to 37 with a median of 19. It was originally intended to represent each range value 20 times per study condition; however, this was precluded due to hardware and software malfunctions in the M-Range automated target system. Therefore, it was decided to randomize target range, which could be supported by the M-Range automated target system.

The sub-sample sizes for range are used to compute both performance metrics. Subsequent statistical analyses assume that all MRE follow the same probability distribution and that all hit ratios follow the same probability distribution; however, nonuniform subsample sizes could lead to biases in various statistical parameters, e.g., standardized coefficients in linear regression.

7.2 Missing Data

As previously described, the M-Range automated target system uses shot microphones located at the shooter's position and behind each target to capture the supersonic signature of rounds that pass through the acoustic envelope, which extends approximately 1 ft outside the perimeter of the E-silhouettes used in the study. The supersonic signature of each round is then converted into an x-y coordinate, relative to the target plane.

Shots that do not pass through the acoustic envelope are not captured and therefore are not assigned an x-y coordinate. However, the MRE for accuracy requires an x-y coordinate for its computation, which necessitates an estimate to substitute for missing data.

The estimation approach follows:

1. Define 2 populations:

   - Population A, shots placed within the acoustic envelope with known, valid x-y coordinates, distributed as normal, (μ_A, σ_A).

   - Population B, shots place outside the acoustic envelope with unknown x-y coordinates, distributed as normal, (μ_B, σ_B).

2. Apply this statistical power equation[12] to both x values and y values:

   $Z_{(1-\beta)} = [(\mu_B - \mu_A) \div \sigma_A] - Z_{\alpha/2}$

   $\mu_B = \mu_A + \sigma_A (Z_{(1-\beta)} + Z_{\alpha/2})$

3. Parameter values as shown in Table 3.

Table 3 Missing data estimation parameter values 3

(x,y)	μ_A	σ_A	$Z_{(1-\beta)}$	$Z_{\alpha/2}$
x	0.5	5.0	1.65	1.96
y	18.4	6.4	1.65	1.96

Note: $\alpha = 0.05$, $\beta = 0.10$, and power = 0.90.

4. The resultant estimate for population B x-y coordinates:

   - For x values:

     $\mu_B = 0.5 + 5.0 (1.65 + 1.96)$

     $\mu_B = 17.6$

- For y values:

  $\mu_B = 18.4 + 6.4\ (1.65 + 1.96)$

  $\mu_B = 23.1$

The coordinates (μ_x , μ_y) = (0.5, 18.4) represent the center of impact (COI) of all shots that landed inside the acoustic envelope. The estimated coordinates for missing x-y values, (17.6, 23.1), represents the COI for shots that landed outside the acoustic envelope. The 2 COI are significantly different with $\alpha = 0.05$ and $\beta = 0.10$.

The E-silhouette aimpoint represents its center mass with coordinates (0.0, 20.25) where $-9.75 \leq \times \leq 9.75$ and $0.0 \leq y \leq 40.5$. The right-most coordinates of the E-silhouette are (9.75, 0.0) and (9.75, 40.5). Operationally, the COI of the shots that landed outside the acoustic envelope (17.6, 23.1) is far right and center of the E-silhouette.

7.3 Principal Components Analysis

The study considered 24 independent variables (anthropometric length dimensions (5), anthropometric ratio dimensions (4), strength parameters (4), rotation parameters (7), sex, range, posture, and weapon) as possible influences on shooting performance. However, it is desirable to reduce that number to a minimally sufficient level to simplify how shooting performance is mathematically represented and to reduce resource requirements and complexity of subsequent actions related to the study objective (e.g., actions intended to improve shooting performance, follow-on studies).

Toward that end, a principal components analysis (PCA) was conducted to determine which independent variables accounted for the greatest degree of variability in the shooting performance data. Of the 24 independent variables, 9 were determined to have met the selection criterion of having an Eigen value ≥ 1 and accounted for 84.5% of the variability in the shooting performance data.

However, subsequent examination of the PCA rotated components matrix to specifically identify the 9 components in question suggested a high degree of correlation among the independent variables to a degree that rendered the results inconclusive. It was anticipated that the rotated components matrix would indicate high component loadings grouped within related variables. For example, one might expect high component loadings among the 4 strength parameters (or length dimensions, ratio dimension, rotation parameters) for a given component. However, high component loadings were observed across multiple variables, regardless of nominal groupings, for any given component.

7.4 Multiple Regression Analysis

A multiple regression analysis was performed to determine whether shooting performance could be mathematically represented as a function of the independent variables.

Results from the previous PCA did not identify specific independent variables that account for the variability in the shooting performance data and also suggested a high degree of correlation among the independent variables. Based on this information, the multiple regression analyses initially included all 24 independent variables and collinearity statistics to evaluate the significance of the independent variables and the degree of correlation among them. In addition, indicator variables for independent variables of nominal data type (sex, posture, weapon, and range) were employed to support comparisons between their respective levels. The reference case for the indicator variables for accuracy and hit ratio is sex = female, posture = reflexive, weapon = HKG36, range = 50 m. These specific values were selected as the reference case to provide an ordinal continuum from small to large.

Examination of the results of regressions performed on both accuracy and hit ratio indicated a high degree of correlation among all anthropometric dimensions and strength and rotation parameters, consistent with the PCA results. The correlation was measured by the tolerance collinearity statistic, which indicates the coefficient of determination (R^2) value for an independent variable as if it were treated as a dependent variable in a regression with the remaining independent variables. A tolerance value ≤0.30 is considered indicative of high collinearity. Tolerance values for the aforementioned independent variables ranged from 0.000 to 0.243, with lower scores most prevalent among the anthropometric length and ratio dimensions.

The next step in the regression analysis entailed iterative regressions on reduced selections of independent variables. Maximizing the tolerance statistic values was the sole criterion for inclusion or exclusion of the independent variables and was subjectively evaluated.

The final selection of independent variables included sex, posture, weapon, range, hand length (centimeters), isometric strength (seconds, support arm) and neck rotation, and horizontal right (degrees).

Multiple regression results and the regression coefficients rank ordered in terms of influence on the dependent variable are illustrated in Tables 4–7.

Table 4 Multiple regression results, dependent variable: accuracy

Model R^2 0.763		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	20.720	2.533	. . .	8.179	.000	. . .	. . .
	Male	–.247	.356	–.031	–.695	.487	.377	2.652
	Posture	–1.773	.213	–.226	–8.341	.000	1.000	1.000
	M4	.718	.260	.086	2.758	.006	.750	1.333
	M16A2	.981	.260	.118	3.767	.000	.750	1.333
	Range 100	2.169	.260	.261	8.332	.000	.750	1.333
	Range 150	6.780	.260	.816	26.045	.000	.750	1.333
	Hand length (cm)	–.440	.113	–.155	–3.886	.000	.466	2.148
	Isometric (s)	–.018	.006	–.114	–2.975	.003	.503	1.987
	Neck horz right	–.043	.011	–.134	–4.094	.000	.687	1.457

Table 5 Multiple regression results, dependent variable: hit ratio

Model R^2 0.765		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	–.045	.211	. . .	–.215	.830	. . .	. . .
	Male	.020	.030	.029	.670	.503	.377	2.652
	Posture	.126	.018	.192	7.112	.000	1.000	1.000
	M4	–.074	.022	–.107	–3.437	.001	.750	1.333
	M16A2	–.036	.022	–.052	–1.668	.096	.750	1.333
	Range100	–.163	.022	–.235	–7.540	.000	.750	1.333
	Range150	–.577	.022	–.832	–26.654	.000	.750	1.333
	Hand Length (cm)	.034	.009	.141	3.567	.000	.466	2.148
	Isometric (sec)	.002	.000	.132	3.473	.001	.503	1.986
	Neck Horz Right	.002	.001	.090	2.747	.006	.687	1.457

Table 6 Regression coefficients rank ordered in terms of influence on dependent variable: accuracy

Variable	Male	Posture	M4	M16A2	Range100	Range150	Hand Length	Isometric	Neck Horz Right
Delta rank	–2	0	–3	–2	0	0	+2	+2	+3
Standardized coefficient	9	3	8	6	2	1	4	7	5
Unstandardized coefficient	7	3	5	4	2	1	6	9	8

Table 7 Regression coefficients rank ordered in terms of influence on dependent variable: hit ratio

Variable	Male	Posture	M4	M16A2	Range100	Range150	Hand Length	Isometric	Neck Horz Right
Delta rank	–2	0	–2	–3	0	0	+2	+3	+2
Standardized coefficient	9	3	6	8	2	1	4	5	7
Unstandardized coefficient	7	0	4	5	0	0	6	8	9

The data illustrated in Tables 4 and 5 indicate a correlation coefficient (R^2) value of 0.763 and 0.765 for accuracy and hit ratio, respectively. The R^2 value indicates the degree of variability in the dependent variable that can be explained by the regression model and is used to assess how well the model can predict future outcomes. A correlation coefficient value ≥0.70 is indicative of an effective regression model.

In terms of statistical significance at $\alpha = 0.05$, sex is not significant for either dependent variable. The constant and M16A2 are not significant for hit ratio. All other independent variables are significant.

The data illustrated in Tables 4 and 5 also indicate values for unstandardized coefficients and standardized coefficients. Standardized coefficients are computed by using the Z-scores (i.e., $\sqrt{n} * (x_i - \mu) \div \sigma$) for the variable in question in the regression computations thereby standardizing the x_i so that their variance is 1.

Standardized coefficients refer to how many standard deviations a dependent variable will change, per standard deviation increase in the independent variable, irrespective of units of measure. As such, they can be used to determine the relative influence of the independent variables, of different units of measure, on the dependent variable.

Toward that end, Tables 6 and 7 illustrate the standardized coefficients and unstandardized coefficients rank ordered, with respect to absolute magnitude, in terms of their influence on the dependent variable. Range and posture have the greatest effect on shooting performance for both types of coefficients. However, standardized coefficients indicate that anthropometric dimensions (hand length, isometric strength, neck rotation horizontal right) are more influential than sex and weapon selection, while the opposite is observed among unstandardized coefficients.

8. Conclusions

In summary, the PCA and multiple regression analysis suggest that 7–9 of the 24 independent variables account for 76%–85% of the variability in the dependent variables. However, the anthropometric dimensions chosen to mathematically represent shooting performance were subjectively selected solely based on the degree of collinearity they exhibited in iterative regression outcomes.

Range and posture had the greatest influence on shooting performance. Shooting performance progressively degraded as the reference value of range increased from 50 to 100 and 150 m. However, shooting performance improved by changing posture from reflexive to prone, the latter generally offering greater stability.

As indicated by the standardized coefficients from the multiple regression analysis, the anthropometric parameters had greater influence on shooting performance than sex and weapon selection. While sex was not determined to be statistically significant, it is implicitly represented in the 3 anthropometric parameters. Table 8 illustrates a statistical comparison of the 3 anthropometric parameters between the 2 sexes. The difference in parameters values is significant at $\alpha = 0.05$ in all 3 cases, which may explain the nominal improvement in shooting performance (MRE for accuracy decreased by 0.247 and hit ratio increased by 0.02 per unit standard deviation) when changing the reference case for sex from female to male in the multiple regression analysis.

Table 8 Anthropometric dimensions comparison

Sex	**Hand Length (cm)**	**Isometric Strength (s)**	**Neck Rotation Horiz Right (°)**
Male	19.8	61.3	83.1
Female	17.8	28.8	73.4

The significance of this finding is that small-arms acquisition programs are commonly required to accommodate Soldiers across the full anthropometric continuum (i.e., 5th percentile to 95th percentile stature), which would include both male and female Soldiers. However, the link between the accommodation and performance is not well understood and, as a result, not linked into requirements. This finding may serve to link those 2 parameters and may inform small-arms materiel development and related combat development.

9. Path Forward

The immediate path forward is to apply the study findings to subsequent shooting studies, which may include unrelated research objectives to verify its efficacy.

Future variations of this study, linking shooting performance to anthropometric dimensions and weapon design, will likely consider more specific metrics to characterize performance effects (e.g., degree of muscle fatigue and weapon center of gravity). Results will be thoroughly documented to support related research and acquisition activities.

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List of Symbols, Abbreviations, and Acronyms

ARL	US Army Research Laboratory
CCO	close combat optic
COI	center of impact
HRED	Human Research and Engineering Directorate
MRE	mean radial error
PCA	principal components analysis

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Appendix A. Trial Matrix: Repeated Measures Incomplete Counterbalanced Design

This appendix appears in its original form, without editorial change.

Note that experimental conditions (e.g. A1, B1, etc) are defined in Table 2.

Participant	Trial-1	Trial-2	Trial-3	Trial-4	Trial-5	Trial-6
1	**A1**	**B1**	**C2**	**C1**	**B2**	**A2**
2	**B1**	**C2**	**C1**	**B2**	**A2**	**A1**
3	**C2**	**C1**	**B2**	**A2**	**A1**	**B1**
4	**C1**	**B2**	**A2**	**A1**	**B1**	**C2**
5	**B2**	**A2**	**A1**	**B1**	**C2**	**C1**
6	**A2**	**A1**	**B1**	**C2**	**C1**	**B2**
7	**A1**	**A2**	**B2**	**C1**	**C2**	**B1**
8	**B1**	**A1**	**A2**	**B2**	**C1**	**C2**
9	**C2**	**B1**	**A1**	**A2**	**B2**	**C1**
10	**C1**	**C2**	**B1**	**A1**	**A2**	**B2**
11	**B2**	**C1**	**C2**	**B1**	**A1**	**A2**
12	**A2**	**B2**	**C1**	**C2**	**B1**	**A1**
13	**A1**	**B1**	**C2**	**C1**	**B2**	**A2**
14	**B1**	**C2**	**C1**	**B2**	**A2**	**A1**
15	**C2**	**C1**	**B2**	**A2**	**A1**	**B1**
16	**C1**	**B2**	**A2**	**A1**	**B1**	**C2**
17	**B2**	**A2**	**A1**	**B1**	**C2**	**C1**
18	**A2**	**A1**	**B1**	**C2**	**C1**	**B2**
19	**A1**	**A2**	**B2**	**C1**	**C2**	**B1**
20	**B1**	**A1**	**A2**	**B2**	**C1**	**C2**
21	**C2**	**B1**	**A1**	**A2**	**B2**	**C1**
22	**C1**	**C2**	**B1**	**A1**	**A2**	**B2**
23	**B2**	**C1**	**C2**	**B1**	**A1**	**A2**
24	**A2**	**B2**	**C1**	**C2**	**B1**	**A1**
25	**A1**	**B1**	**C2**	**C1**	**B2**	**A2**
26	**B1**	**C2**	**C1**	**B2**	**A2**	**A1**

Appendix B. Demographic Data Form

This appendix appears in its original form, without editorial change.

Demographic Data

Participant Number ________ Age_____ Gender ____

Height (cm)__________, Weight (kg)________

Are you left-handed ____, right-handed ____ or ambidextrous____?

Are you a left-handed ____or right-handed ____rifle shooter?

Do you use your ____left eye or ____right eye to aim a weapon?

Visual Acuity

Do you wear prescription glasses or contact lenses when you shoot? Yes ___ No ___

Snellen and Miles Test Results (circle which eye is dominant):

Left Eye__________ Right Eye___________

Military Experience

Date of most recent Military Service (MM/DD/YYYY – MM/DD/YYYY): __________________

Branch: ______ Primary MOS______ Secondary MOS______

Indicate date (MM/YYYY) of most recent weapons qualification in table below:

Qualification	M14	M16A2	HKG36	Other (specify)
Marksman	____________ Date	____________ Date	____________ Date	____________ Date
Sharpshooter	____________ Date	____________ Date	____________ Date	____________ Date
Expert	____________ Date	____________ Date	____________ Date	____________ Date

Anthropometric Measures

Length Measures (cm)

Grip Reach	Shoulder-Elbow	Forearm-Hand	Hand Circum.	Hand Length

Length to Grip Reach Ratios

Shoulder-Elbow	Forearm-Hand	Hand Circum.	Hand Length

Range of Motion (degrees)

Neck Horizontal	Torso Horizontal	Internal Shoulder Rotation	External Shoulder Rotation	Back Flexion

Strength and Endurance

Maximum Contraction (lbs)	Isometric (seconds)	Endurance (max. count)	Grip Strength (lbs)

Appendix C. Posttrial Questionnaire

Participant Number _____ Date ________________ Condition _______________

Answer each question once by checking the response that best represents your opinion.

	Strongly Disagree	**Disagree**	**Neither Agree or Disagree**	**Agree**	**Strongly Agree**
The weapon's length adversely influenced my performance.					
The weapon's weight adversely influenced my performance.					
The weapon's recoil adversely influenced my performance.					
Long range adversely influenced my performance worse than short range.					
The firing position adversely influenced my performance.					

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